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Precipitation forecast challenges and possibilities

URBAN PREX
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MOTIVATION

- Recent successful contribution to urban heat island modeling have encouraged us to design a numerical weather prediction system for the short and medium term forecasting of urban extreme precipitation.
- Such a system requires special infrastructure tailored for the designated target, including
  - state of the art, high performance computing resources (Hardware)
  - adequate and properly set limited area numerical weather prediction simulation models (software)
  - proper input data (geographic/static and meteorological/time dependent)
  - high resolution precipitation data (local precipitation measurements) for verification and model parameter tuning
  - post processing
  - visualization and data delivery

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CHALLENGES

- Contrary to UHI, extreme precipitation events are governed by non-local factors, i.e., remote effects
- Precipitation pattern highly variable in time and space (even the detection of events is problematic)
- Various types of heavy rainfall weather situations requires a wide scale of modeling approach
  - Convection (Thunderstorms with heavy showers)
  - Upper level cold vortex (Cold “droplet”)
  - Mediterranean low (“*Geneva*”-type cyclones)
  - Embedded convective cells in occluded frontal systems of cyclones detached from the polar front
  - “*Medard*”, the European monsoon
- Different challenges require different solutions: Different ~
  - scales
  - motions
  - forcings
  - balances
- → Different modeling approaches

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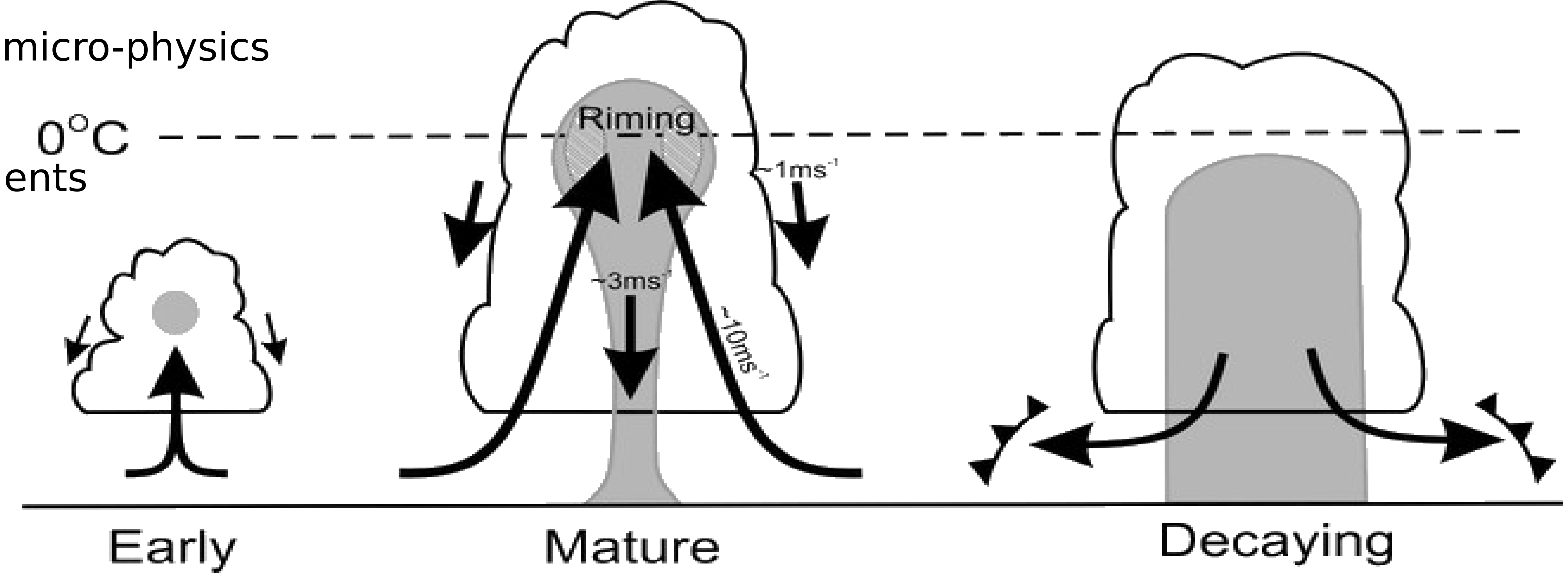
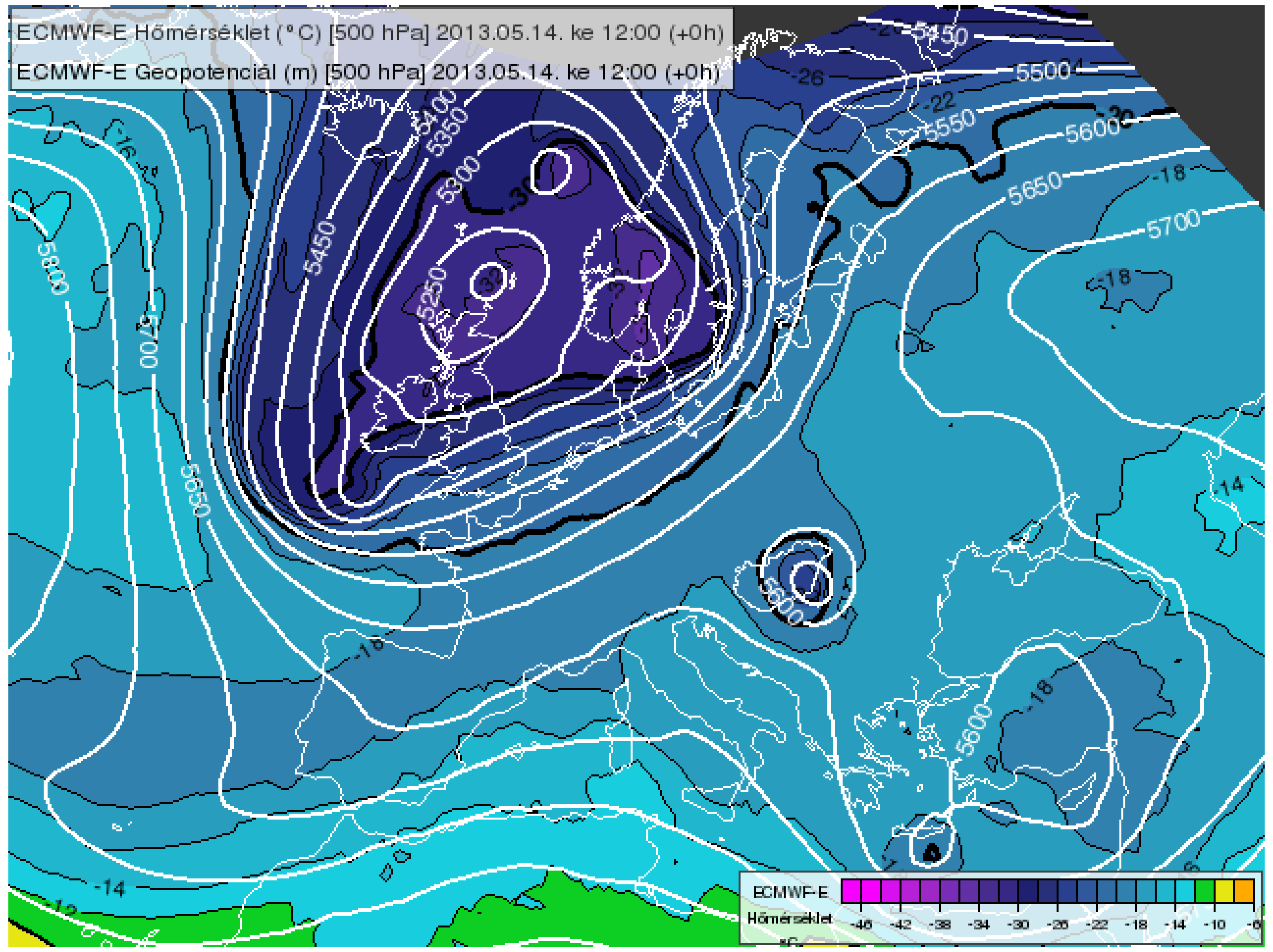
Convection

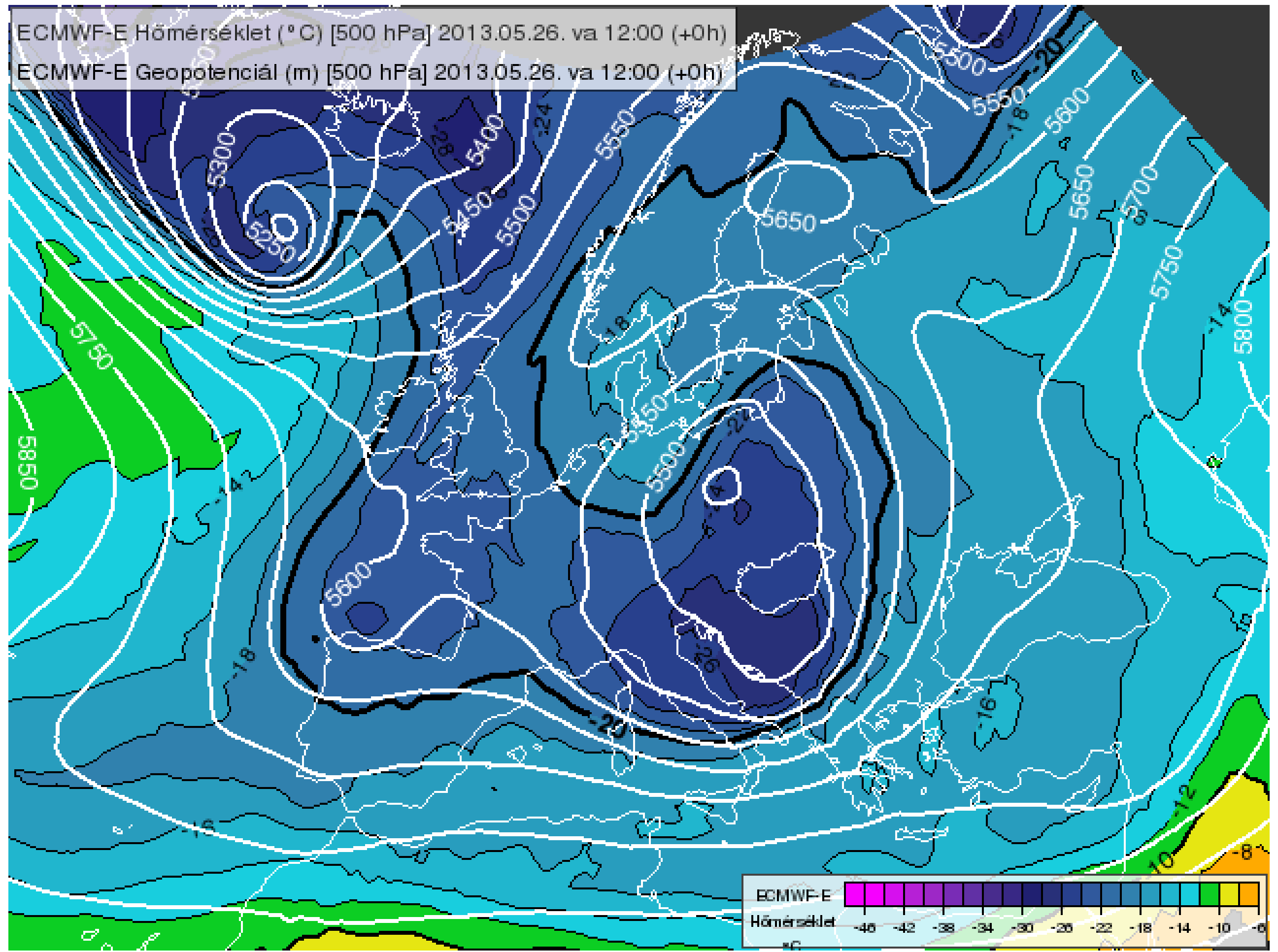
- Spectacular, severe, extensive literature
- Challenges
  - resolved and parameterized scales – gray zone
  - micro-physics
  - stability
  - precipitable water
- Possibilities
  - high resolution nested modeling
  - multi-momentum and multi-phase micro-physics
  - GNSS data
  - local radiosonde or UAV measurements



Upper Cold vortex

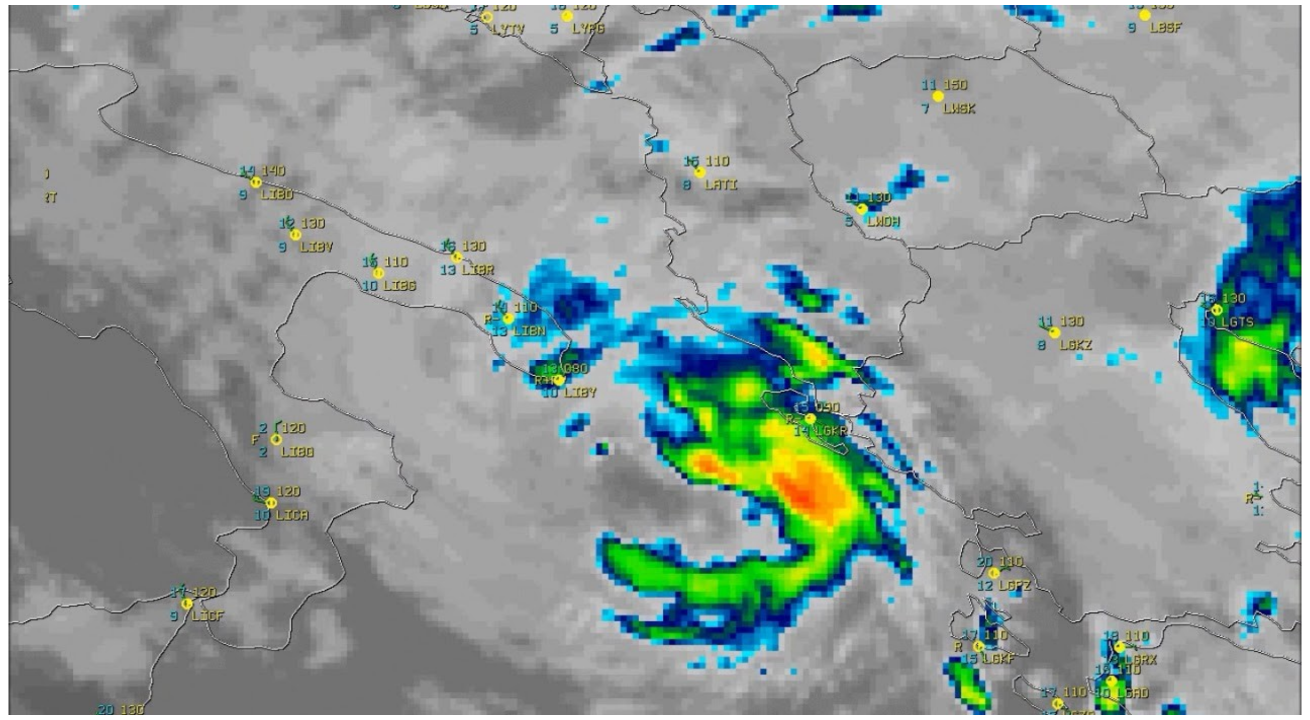
- Challenges
  - Upper troposphere (P<500hPa) cut-off low cold anomaly (April – June)
  - Positive relative potential vorticity
  - At near surface level usually nil cyclonic circulation nor depression
  - Several hundred kilometer extension
  - Intensive deep convection (TS SH) activity, especially in summer
  - Linked to upper cold trough
  - Sources at data sparse area
  - Highly unpredictable trajectory
- Possibilities
  - Larger simulation domain (including polar regions)
  - Better (global) input data – different global driver model
  - Different representation of baroclinic effects (fine tuning of the so-called model dynamics)

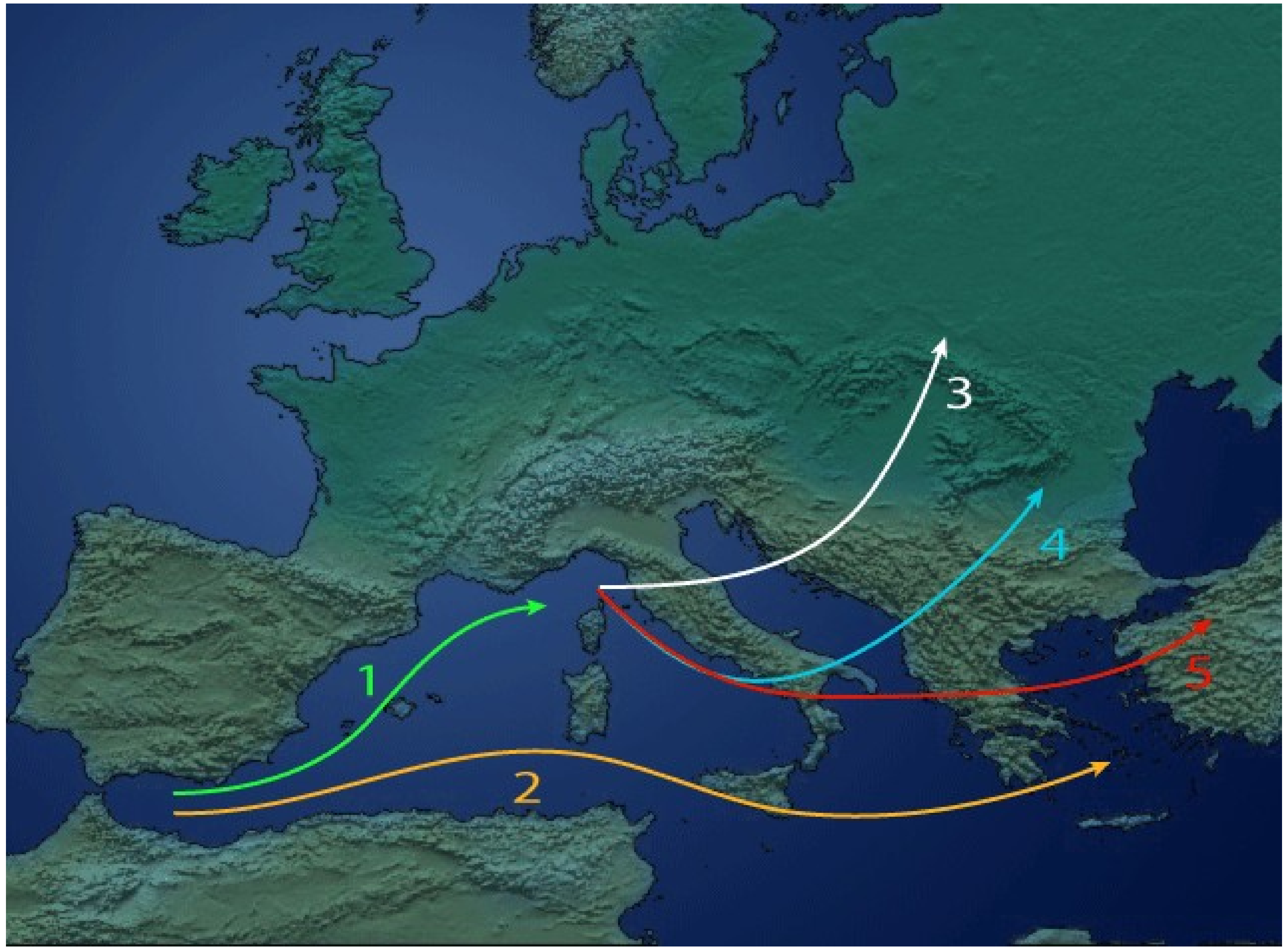




Mediterranean low

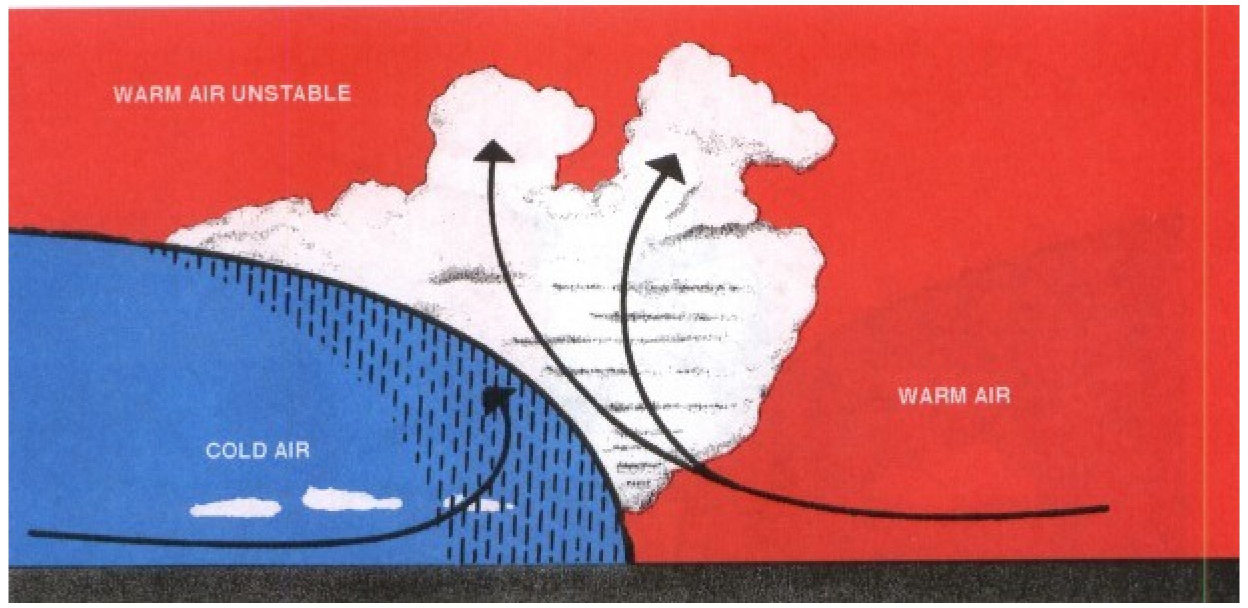
- Meteorological terminology: mid-latitude cyclone, baroclinic and diabatic forcing, more frequent in winter semester
- Challenges: Lee-side depression over the Alps, SST of the Mediterranean, Land-surface interactions
- Similar characteristics to tropical cyclones
- High frq. cyclones – most cyclogenetic region in the world
- Affected by local flows (Mistral Bora)
- Relatively shallow system
- → Highly unpredictable trajectories
- Possibilities
  - mid resolution nested modeling
  - costly micro-physics
  - satellite data

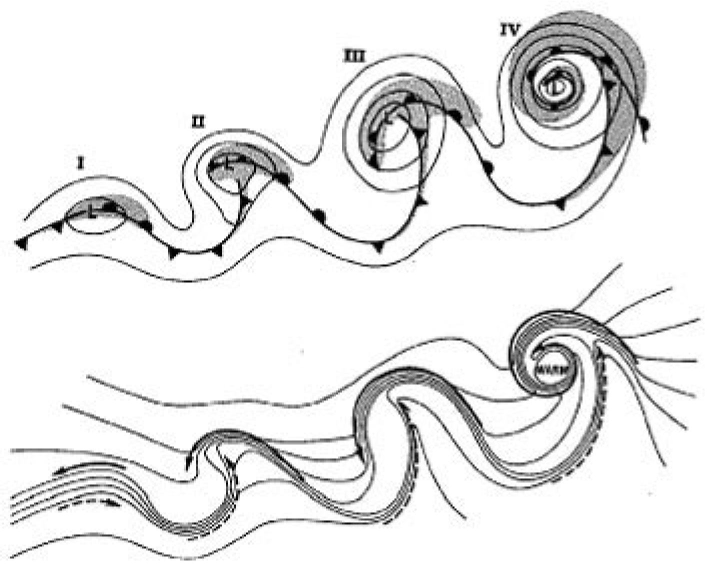


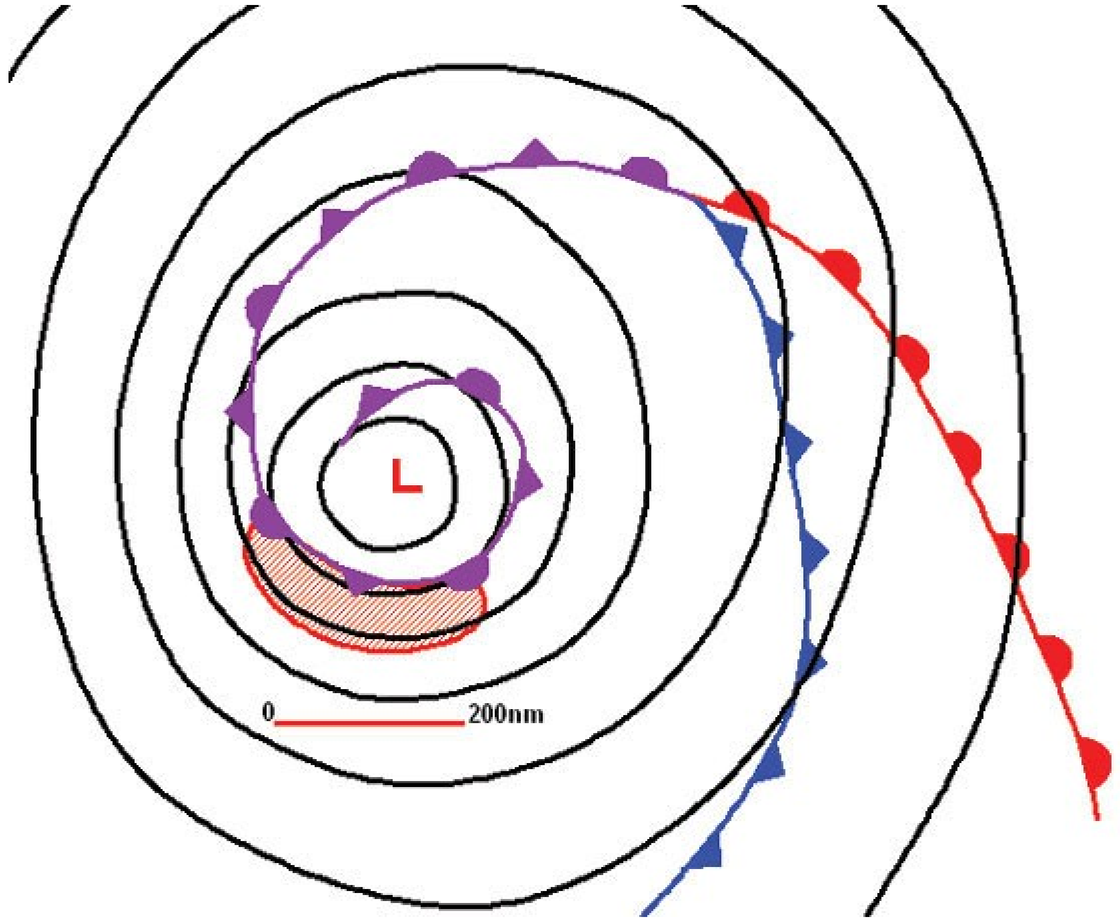


Embedded CB in cold occlusion

- Cold occluded front underrunning warm, moist air.
- Huge stratiform cloud system with embedded Cb and TS
- Challenges:
  - Wide scale of features from synoptic to micro-scale effects
  - Energy cascade with multi-scale interactions
- Possibilities:
  - resolution (both vertical and horizontal
  - microphisics
  - Convectice schemes







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European monsoon

- France: St. Gervase/St. Protais (19 June); Belgium St. Godelieve (6 July); Germany 27 June; UK St. Swithin (15 July).
- Seasonal variation of circulation pattern
  - moist maritime air cyclonic activity → drier airmass from SE High pressure dominance
- Challenges: with the change of circulation patterns the best practice modeling approaches change
- Possibilities: model setup for different seasons (or even different synoptic situation)
  - this approach requires an order of magnitude more computational resources and an enormous human labor for the analysis of output data

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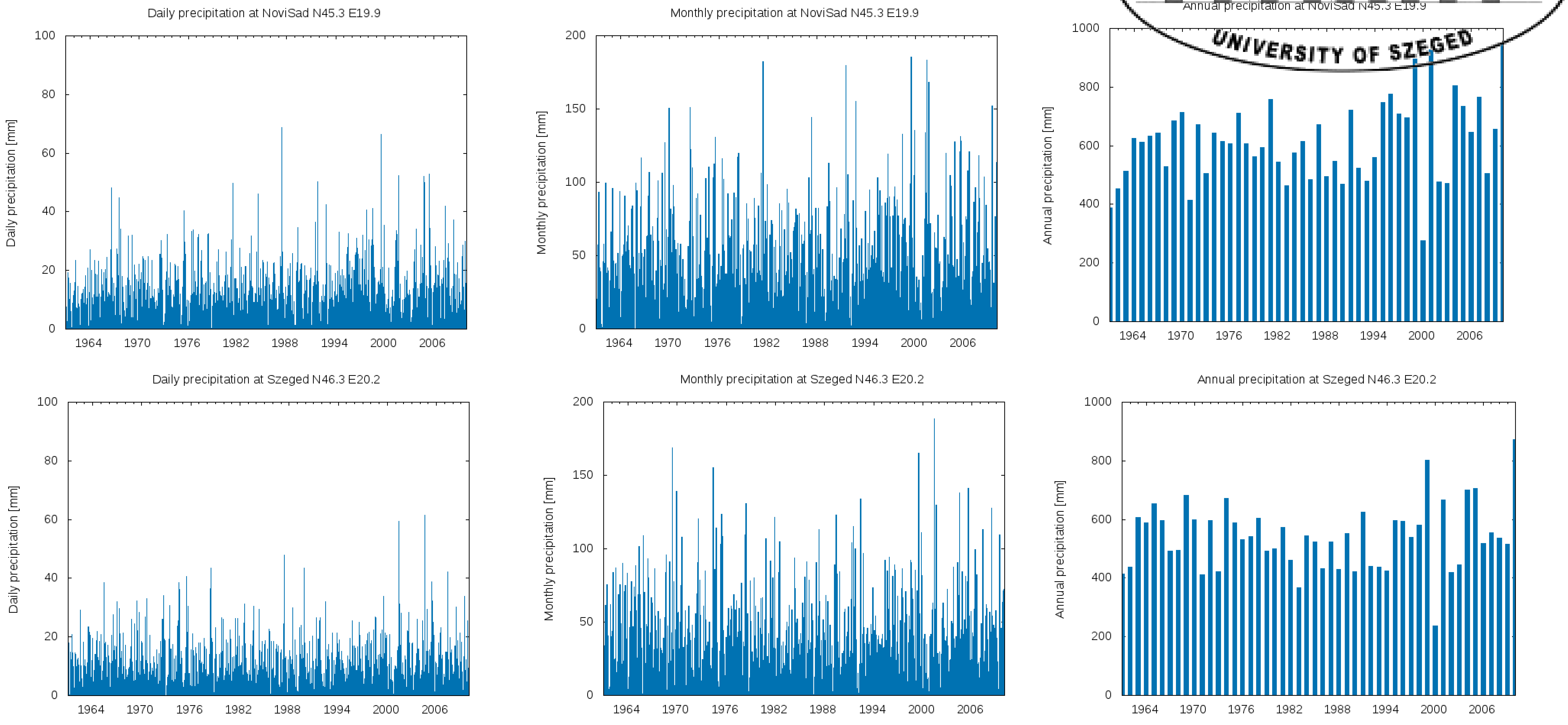
Inter-annual variability



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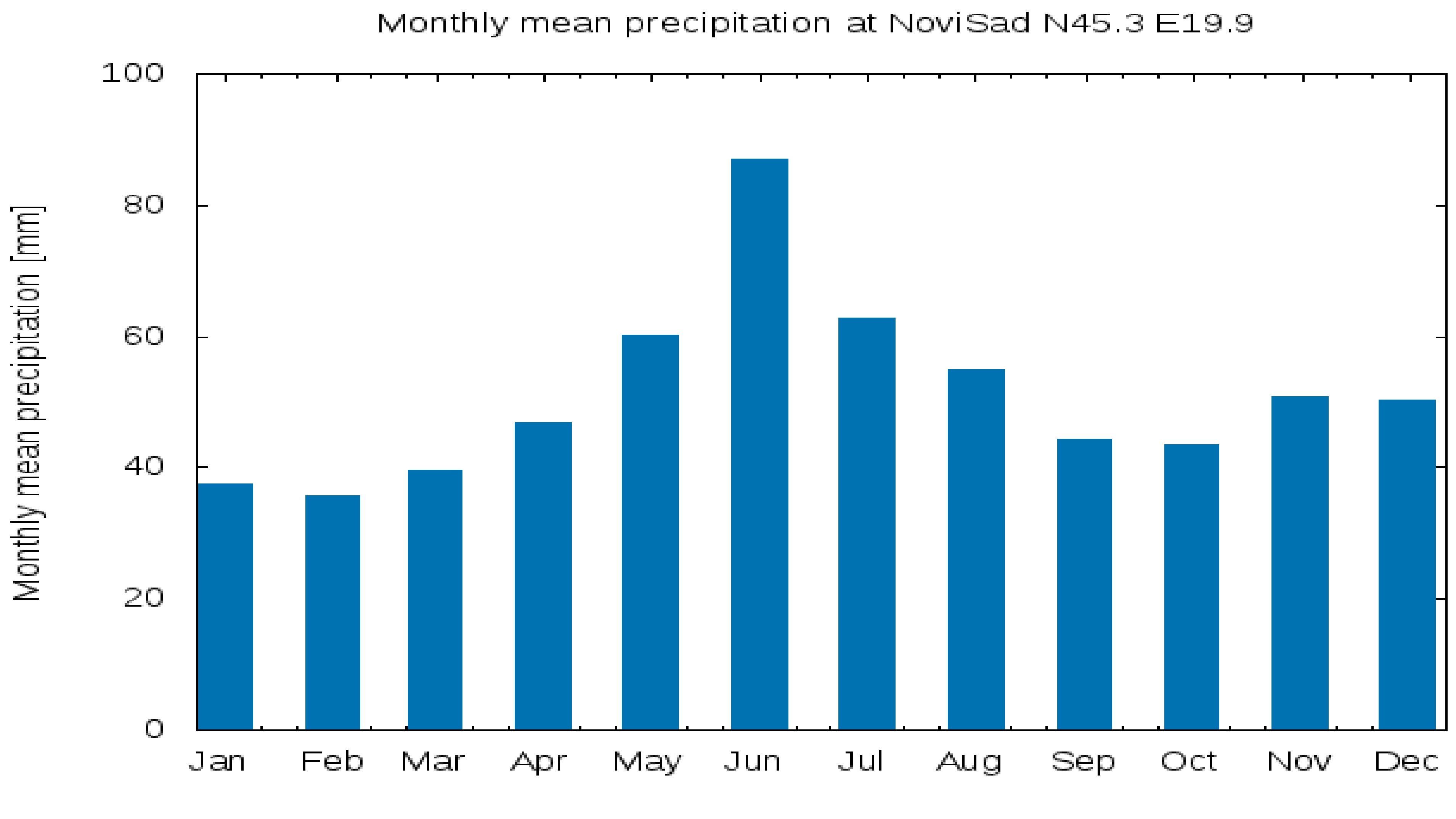
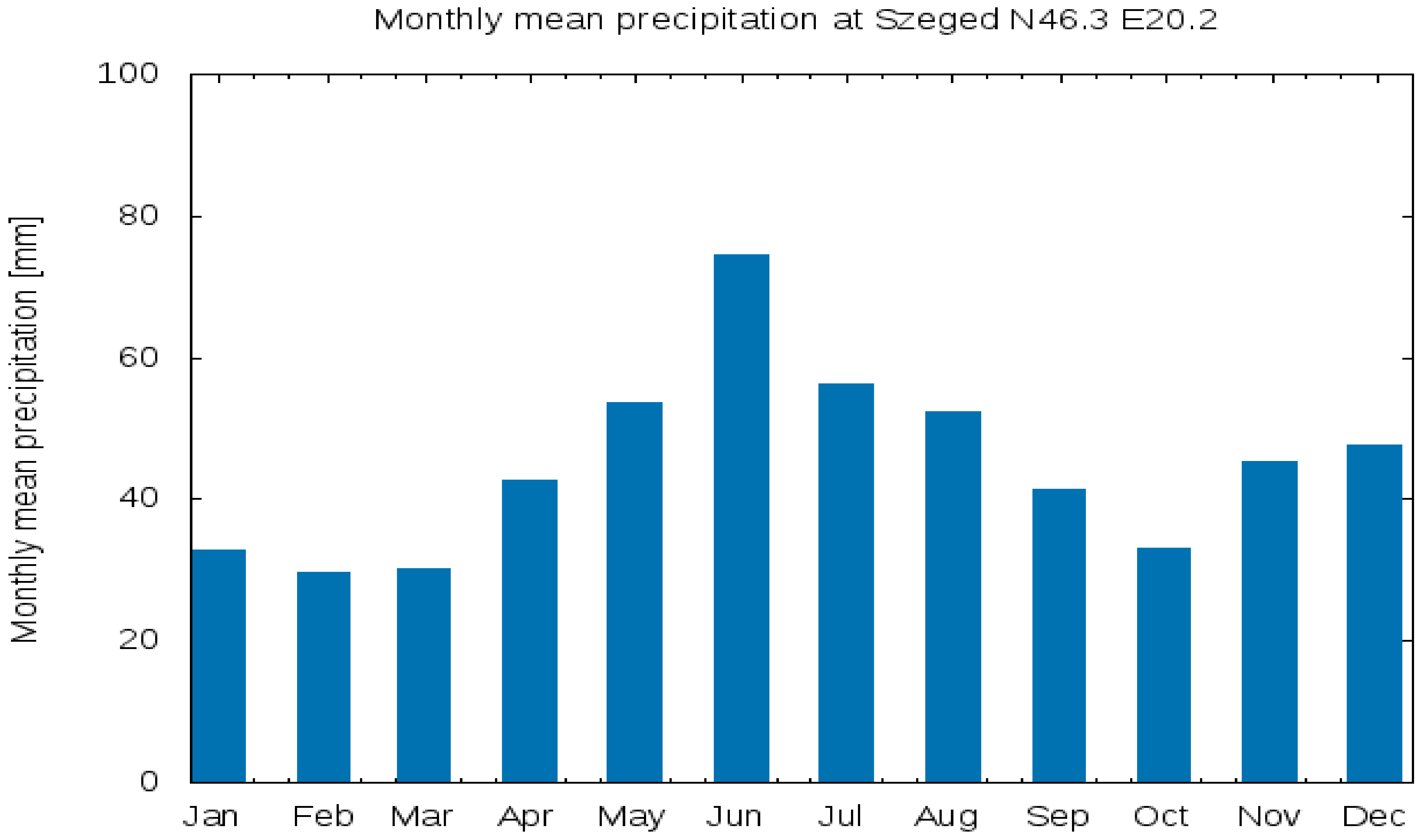
Seasonal variation





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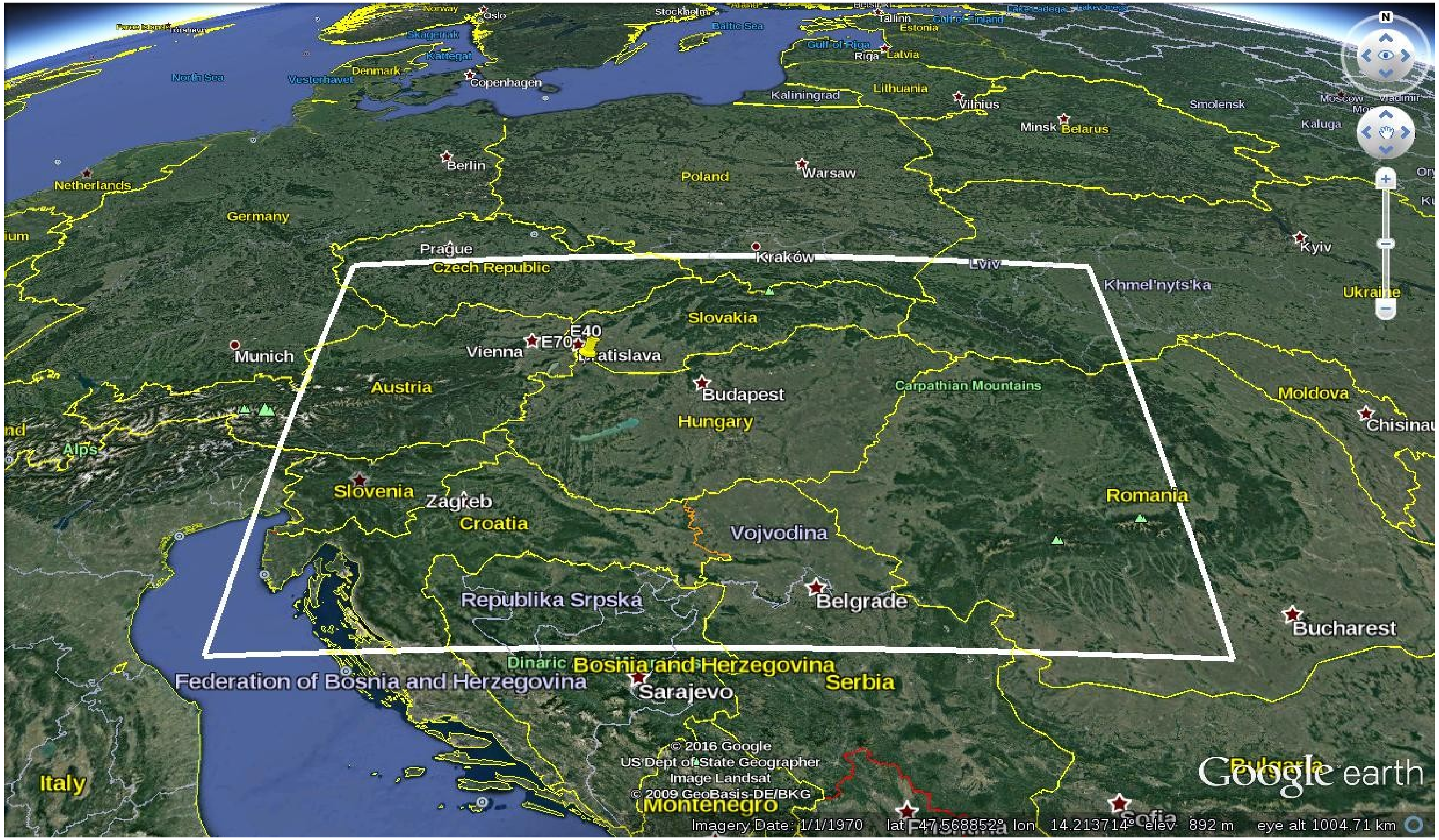
Numerical Weather Prediction

- Modeling approach
  - Based on the current state of the atmosphere (input data)
  - Conservation (Energy, mass) → physical relationships → mathematical equations → numerical solution (model)
  - Forecast state of the atmosphere (output data)
- Challenges
  - Input data deficiencies (sparse, inadequate, contains errors, especially data from the free atmosphere)
  - Model weakness (unresolved effects are poorly represented, such as turbulence, convection, radiation, micro-physics of cloud and precipitation formation, land-surface interactions, planetary boundary layer etc.).
  - Output data processing (visualization, post-processing, interpretation of probabilistic results and integral quantities, such as precipitation water or CAPE for our purpose).
- Possibilities
  - Increasing horizontal resolution to resolve smaller scale effects → but this requires more detailed input data (both geographical and meteorological);
  - Increasing vertical resolution to better represent boundary layer features
  - Fine tuning of parameterization of unresolved phenomena → but this is very often a function of the scope of our interest of the weather situation and this requires an order of magnitude more integration (costs).

Model representation of processes on a finite grid mesh

- different resolution nested domains



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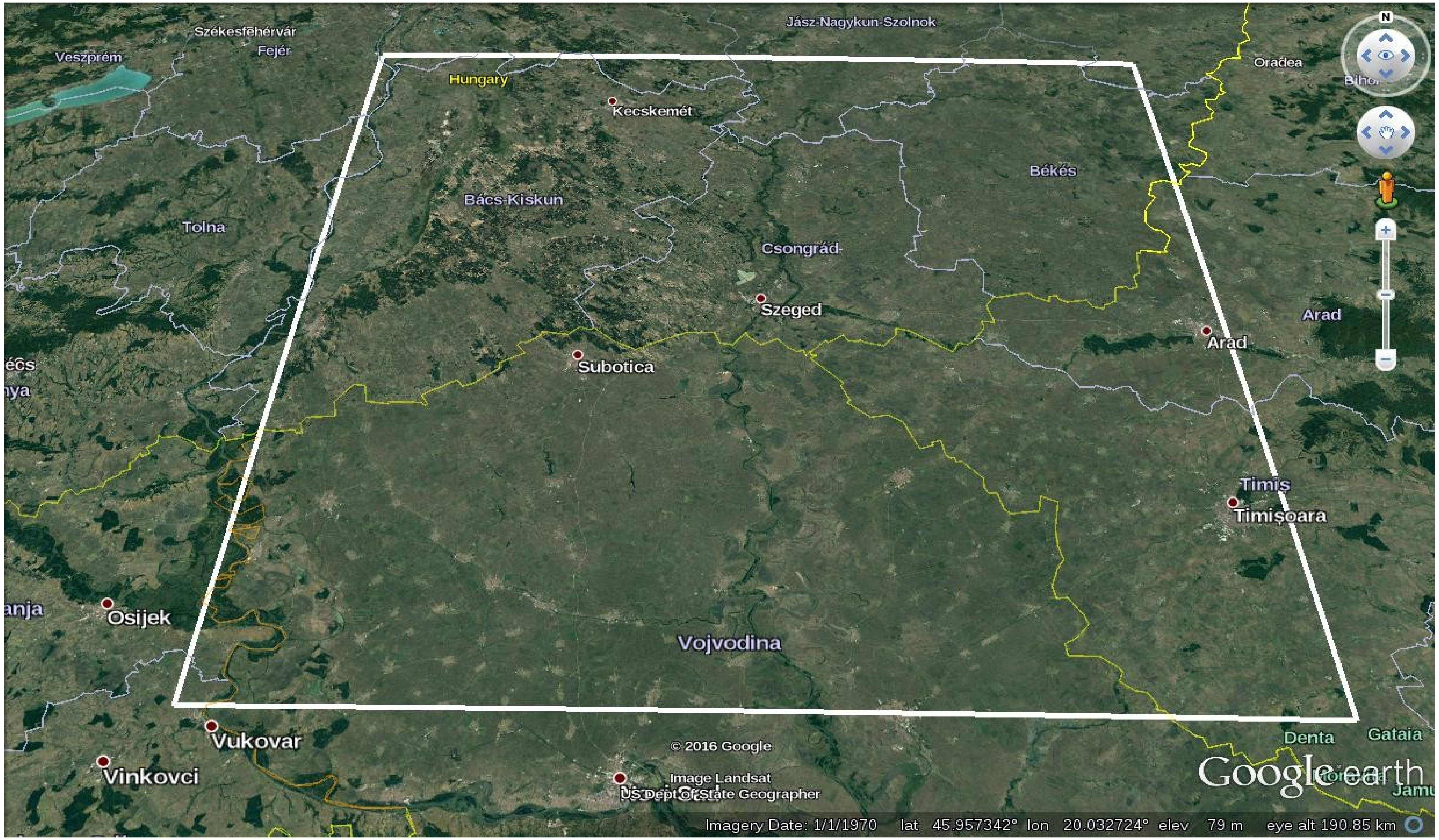

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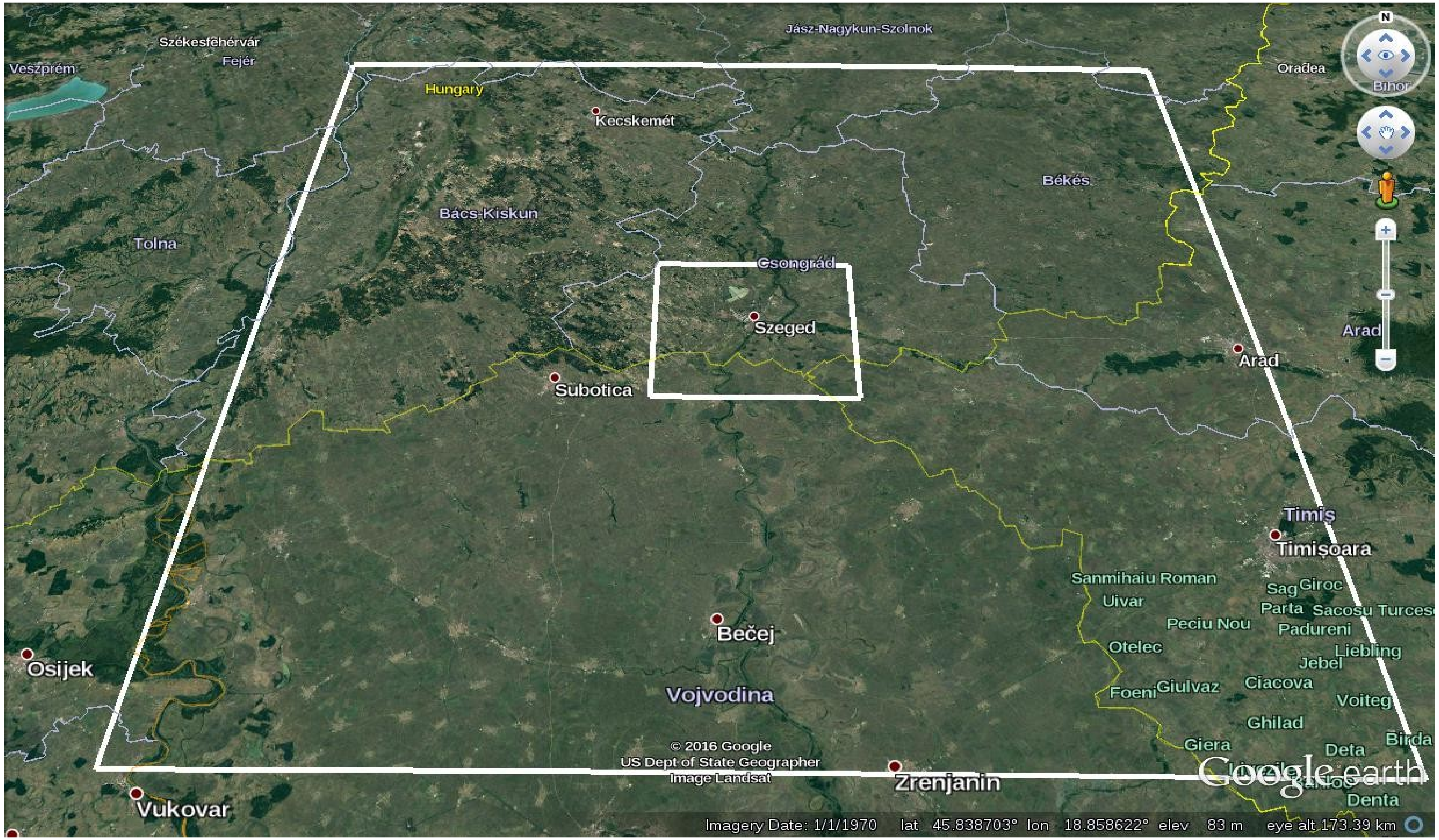

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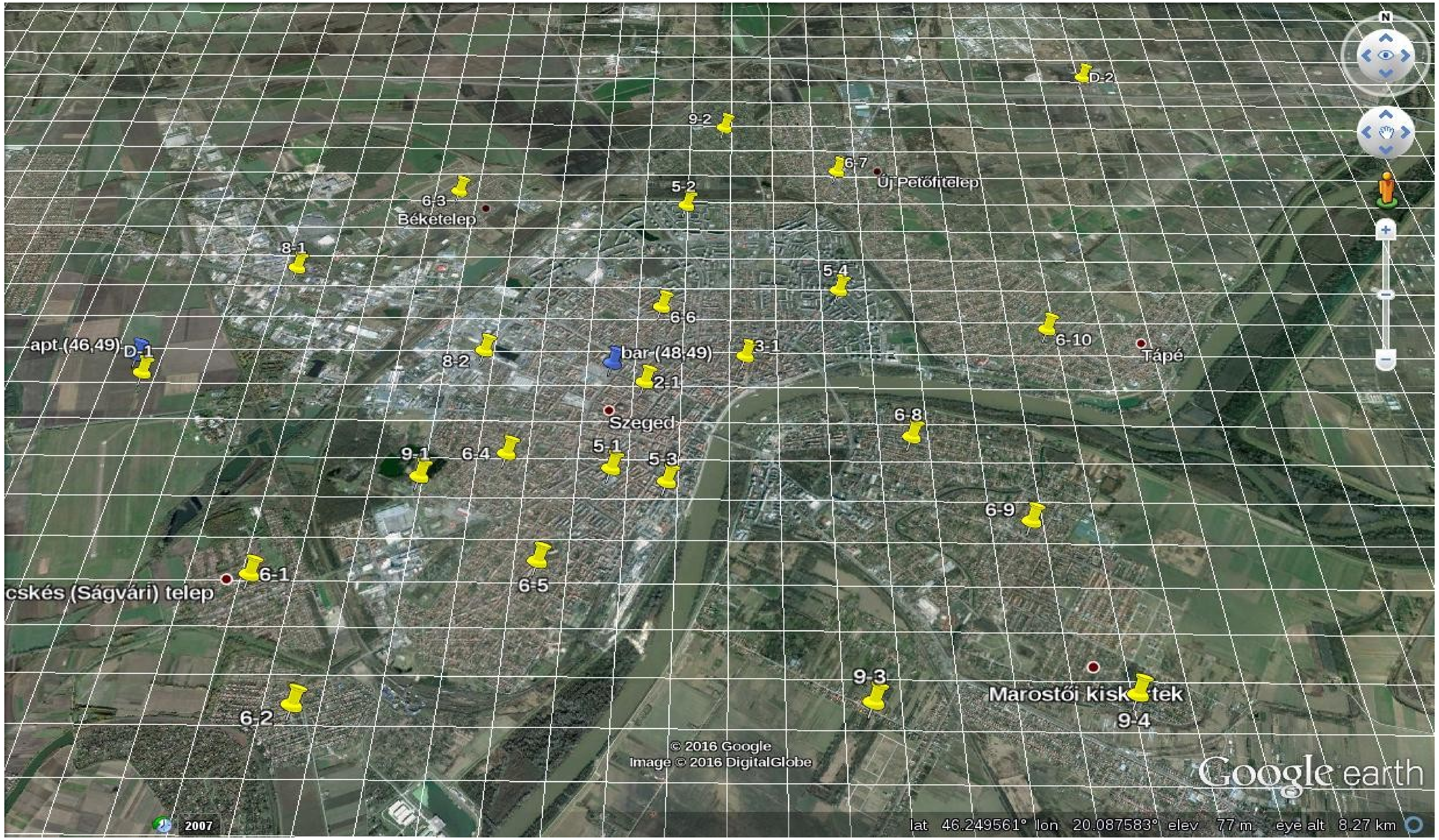
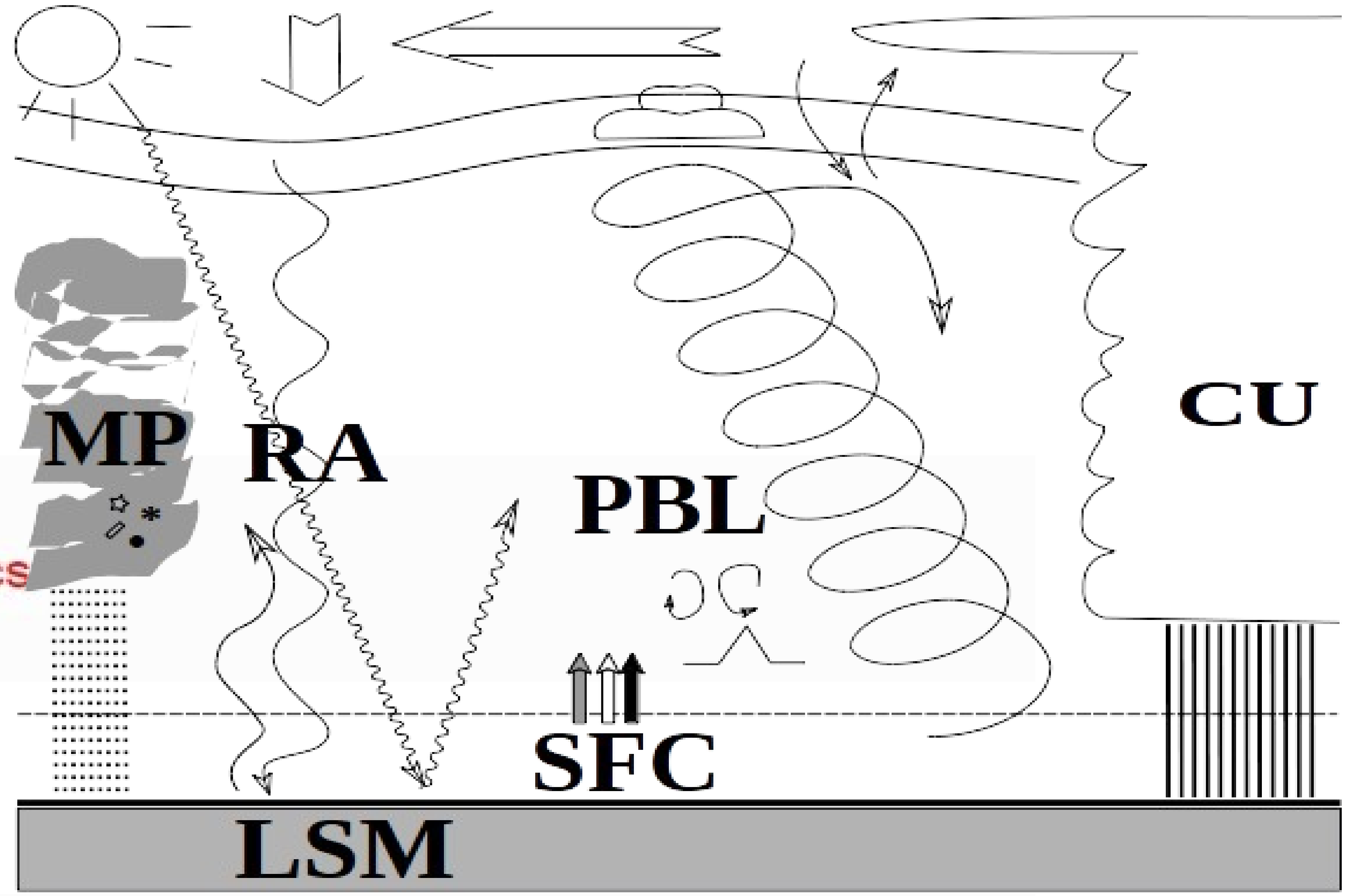
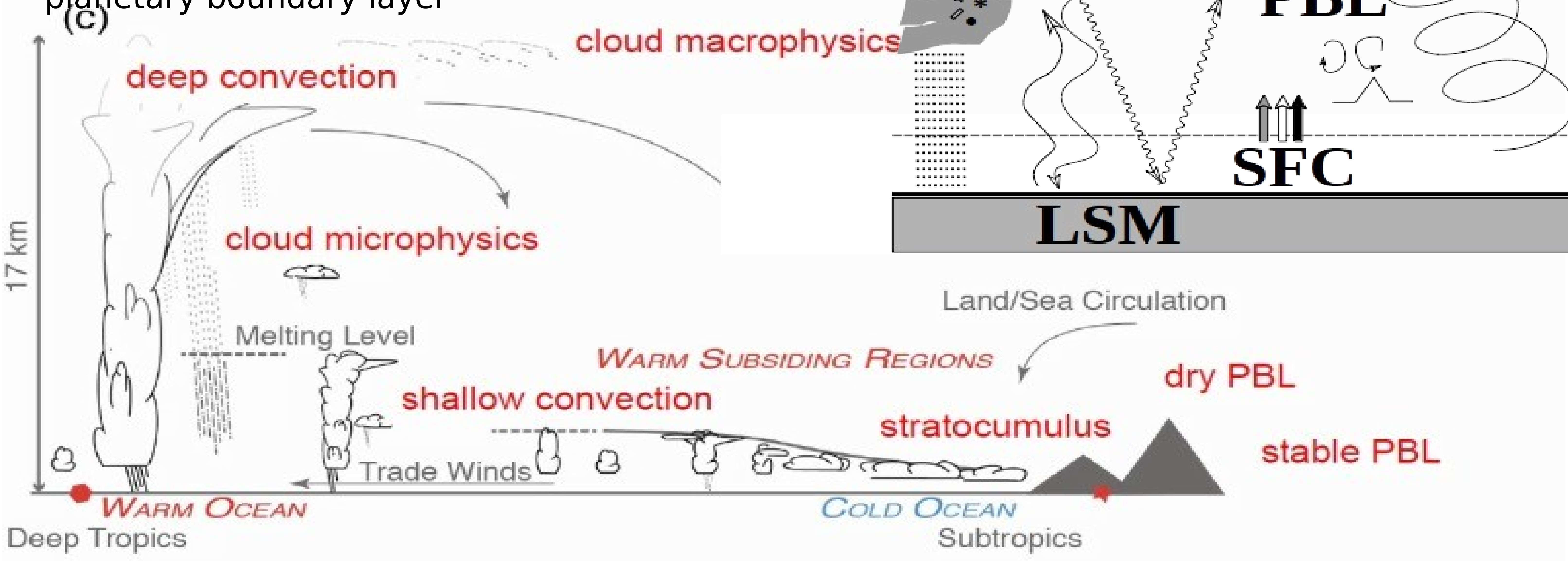


Parameterization of “Physics” in NWP models

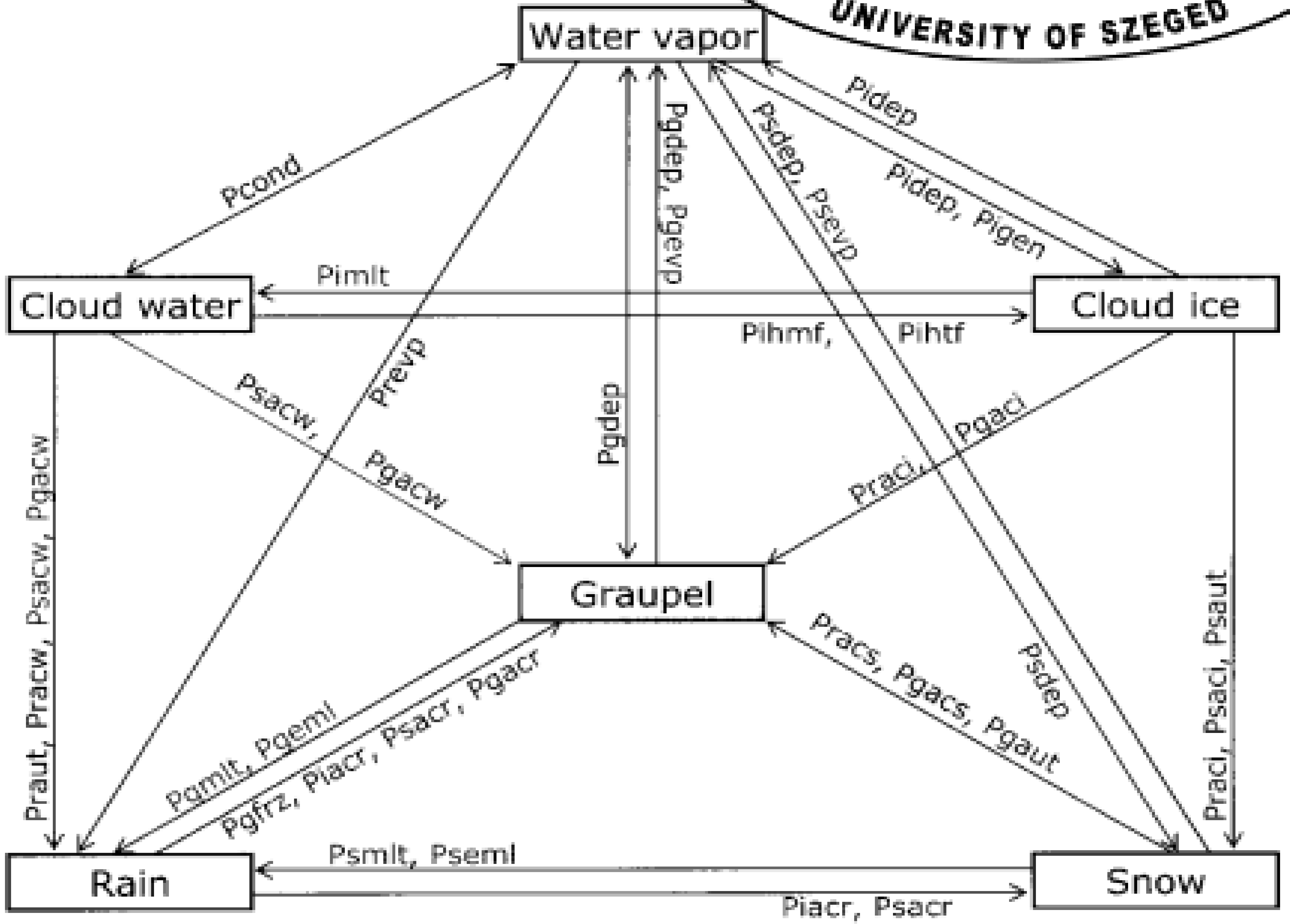
- Unresolved processes
  - turbulence
  - convection
  - radiation
  - micro-physics of cloud and precipitation formation
  - land-surface interactions
  - planetary boundary layer





Parameterization micro-physics of cloud and precipitation

- Micro-physics parametrization
  - 6 class of hydro-meteors
    - vapor
    - cloud water
    - cloud ice
    - graupel
    - rain
    - snow
  - single momentum
    - only number concentration (or mixing ratio)
  - Physical processes of phase change and
  - fall out velocity are considered
- Key factor in our scope of interest, but
- Very expensive computational cost



Weather Research and Forecasting

- Highly scalable community development mesoscale NWP model with a massively parallel portable software architecture
- Serves wide range of meteorological applications: n x 10m → n x 1000km
- Free input and static data available (GFS, continuously improving but far from the best global model);
- Wide range of parameterization options, yielding several million possible model setup configurations
  - recent advances of physics
  - numerics
  - data assimilation
- Large worldwide user and developer community worldwide (~40 thousand from 160 countries) offering a huge pool of testing, information and common knowledge
  - WRF Users page
  - Workshops
  - Tutorials
  - Newsgroup
  - Forums

Recent achievements

- For a slightly different application (aviation meteorological support and urban heat modeling) recent modeling activities serve solid basis for further application
  - Static data locally specified
    - DKSIS soil data (currently available only for Hungary)
    - CORINE European landuse/landcover information
    - Urban canopy information with geometric parameters and building data
  - Several parameter setup has been tested on specially selected case studies and the best practice model setup has been chosen for the given location and given application
- This approach may be applied to our future development in order to obtain an optimal setup for the prediction of extreme precipitation events in the Pannonian region.
- This requires extensive precipitation measurement data since the spatial distribution of precipitation amount has a highly varying pattern.
- Precipitation measurements may be applied both for verification (fine tuning of model setup) and further data assimilation, i.e., serving as actual input data for further operational model integration (soil moisture and surface energy balance requires such data)...

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Suggested development

- Selected situations (n x 10 weather cases)
  - Convection
  - Cold vortex
  - Mediterranean low
  - Cb embd
  - EU Monsoon
- Fine tuning of parameterization (n x 100 setup per cases)
  - PBL, micro-physics and LSM schemes
  - nesting (horizontal and vertical)
  - static data
  - dynamics (boundary conditions)
  - data assimilation
- Application of software containers to be run in docker environment
- Statistical verification over experimental and operational (SYNOP, TEMP, METAR, etc.) measurements
  - several thousand results of data series and fields
  - several hundred observation
  - definition of a “cost function” to represent the forecast accuracy/error
  - minimize the error with respect to the model setup

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Further development

- Besides aforementioned model development...
  - visualization and verification methods shall be improved in order to support the development efforts
  - output data post-processing
  - data delivery and conversion to human-readable format (Gigabytes of output data matrices that shall be represented in a form which can be ingested by non-meteorologist users and partners

This latter probably requires even more intuitive thinking approach and much more original idea than the “normal” usual meteorological research

- Looking forward to the challenge!
- Thank you for your attention

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